Designer Centred Development of a GA-Based DSS for the Conceptual Design of Buildings

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ABSTRACT

Research into computer assisted design is often undertaken with relatively little input from practising designers. Without such involvement one can argue that the techniques developed are not subjected to any form of evaluation or independent scrutiny and therefore the methodology is wanting in terms of scientific rigour. The paper describes a research project to examine the use of evolutionary computing techniques for the design of commercial office type buildings. The research has involved a considerable amount of input from designers and the contributions that they make to the research are identified and discussed. In particular the benefits gained from their evaluation of the software are considered. Also the possible pitfalls regarding such an approach to research are identified.

Key Words

Evolutionary Computation: Conceptual Design: Buildings, Office: Program Evaluation

Introduction

In general, the uptake of advanced Information Technology (IT) techniques by the construction industry has been disappointing, particularly considering the amount of research output. Although there are some islands of success such as analysis, spreadsheets and drafting packages, the majority of IT techniques and tools see little usage except for specialist applications. It is interesting to look at some of the explanations for the poor uptake

Futcher (2000) reports a survey of Hong Kong's usage of construction IT which revealed that even the digital transfer of information within companies was not commonplace. He attributes the lack of IT usage to the fact that

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the construction industry is highly fragmented and hence relies heavily on inter-personal communication. He does think there is a place for IT but that it needs to be fully integrated with human practices.

In 1994 there was a workshop at Carnegie-Mellon on the Future Directions of Computer-Aided Engineering (CAE). This looked at all areas of Engineering not just the construction industry. One group of papers in this workshop while ostensibly addressing the future of CAE, interestingly looked at reasons for the take up of advanced IT techniques by industry. Dym & Levitt (1994) attribute the failure of AI-based software to the fact that it tends to operate in the very areas that engineers feel is their core activity, the synthesis of solutions. This point of view is supported by Parti (1994). However Reich (1994) is much more hard hitting – *"Instead of studying computer facilities for aiding engineers, CAE researchers study computer-aided engineering often in isolation from engineers. This isolation allows researchers to employ whatever interpretation of engineering they wish"*. This stance is supported by Betts (2000) who says "*Our research focus has been the big fundamental technological solutions of construction's problems by developing advanced technology demonstrators.... that illustrate how construction information management should be practised in an ideal world"*.

Smith (1996) focuses solely on design and postulates that the fault lies in the fact that "*....current interactive design capabilities and knowledge representation schema are not compatible with most design tasks"*. This implicitly agrees with Reich and Betts that there has been too much emphasis on technique development and not enough on studying what industry needs and more particularly what it will accept. It can be postulated that the research impetus for CAE has placed too much emphasis on the techniques that are emerging from computer science.

This paper examines the development of a design tool called BGRID which uses a Genetic Algorithm (GA) as a search tool, to investigate the design space and present the user with a number of 'good' solutions. The research was undertaken in close collaboration with practising designers. The aim of BGRID is to assist members of a design team at the conceptual design stage of the creation of multi-storey office buildings. The system helps designers to develop a strategy in terms of spatial characteristics, structural and building services systems and concentrates on key first-order decisions using an integrated approach. Full details of BGRID are contained in Sisk (1999).

BGRID's development process can be divided into two main stages and it is the purpose of this paper to describe this development and how it was influenced by an evaluation process. The evaluation was undertaken by practising designers and involved both short term and longer term testing. Evaluation of research systems is an area which has been shown to yield useful information (Miles et al, 2000) but which is rather neglected by the research community. This paper looks at what can be gained from a thorough and independent evaluation and also the potential drawbacks of using such an approach.

Related Work

Others have applied evolutionary computing techniques to the conceptual design of office buildings. Khajehpour & Grierson (1999) describe a GA based system which finds the Pareto optimal design of a building using a multi-criteria objective function. Their work includes as variables, the various grids, structural systems, HVAC, building height and number of storeys. This gives a large search space which is only constrained in terms of required floor area, soil properties, extreme outside temperatures (they are based in Canada) and planning requirements. The results are presented to the user as a set of filtered Pareto surfaces which show the trade off for the major variables between cost and revenue. The system has been developed without any significant industrial involvement.

Rafiq et al (1999) have developed a GA based tool for the design of office buildings using a Neural Network (NN) in the objective function. The system is limited to concrete frame buildings and includes as constraints the minimum and maximum number of stories, preferred storey height, site dimensions, building footprint (optional), various grids, loadings and light requirements. In addition the system also asks for costs of materials, land and labour. The variables are number of storeys, floor width, bay dimensions, and the ratio of beam width to depth. At the start of their work they consulted architects, structural engineers and quantity surveyors and used this information to verify the software. Their system produces a single optimal design although information regarding other options produced by the GA can be accessed by the user.

A significant contribution to the use of evolutionary computing for conceptual design has been made by Parmee (1998) who has developed a filter search tool which identifies regions of high performance in a multi-dimensional search space.

Initial Philosophy

The motivation for the development of BGRID was to assess the transferability of technology previously developed for the conceptual design of bridges (Miles et al, 1995) (Moore et al(1997) to the conceptual design of office buildings. With bridge design, the search space is relatively limited and hence there is no need for a search engine (Foley et al, 1999). With office buildings, the greater complexity is such that this approach is not suitable. Previous experience on other work has shown that GAs are suitable for this type of work and others have reported success in using them for building design (Mathews & Rafiq, 1995) so it was decided to use a GA based search engine.

The high degree of organisational fragmentation in the Architecture, Engineering and Construction (AEC) industry is well known. Typically in the conceptual design of a building there are 4 major types of designer, these being the architect, the structural, the building services and the geotechnical engineer. In addition others are involved such as quantity surveyors and of course the client. It was decided to concentrate on the superstructure of the building, thus excluding the geotechnical engineer but it was felt that the system should be multi-disciplinary, thus being useful to the other 3 designers and possibly also the client and the quantity surveyor.

The aim of BGRID is therefore to support a multi-disciplinary team undertaking the conceptual design of an office building to develop a design strategy in terms of spatial characteristics, structural system and building services. To achieve this it is necessary to focus on the first-order decision. Previous work (Miles at al, 1995) has shown that it is essential to support rather than replace the designer in the decision making process and so the style of the system has to be that of a Decision Support System (DSS) using the GA as a search tool to provide the designer with feasible options rather than as an optimiser. To achieve this a system needs the following characteristics :-

- The system should enable designers to quickly explore and examine a wide range of options;
- The system should allow the designer to use his/her experience in the reasoning process;
- The system's reasoning should be transparent so that users can assess the accuracy of the solutions.

When developing a DSS in conjunction with designers, one can either start by talking to designers and then building a system based on their suggestions or develop a prototype and use this as the basis for development. The former has the advantage that one starts with a completely open mind about the style and functionality. Past experience has shown that this can produce useful results (Cadogan, 1998) but that designers have a limited knowledge of IT and so are unable to envisage the full range of possibilities. As the need for a powerful search engine had already been determined, it was decided to use the second approach and build a prototype. In such a situation it is generally better to build a high quality prototype rather than use rapid prototyping. The problem then arises of how to find enough good quality information to build a prototype. Fortunately the UK Steel Construction Institute (SCI) produces a design guide (SCI, 1998).

Stage I Development

This stage of development is the work that was undertaken to create the initial prototype. It will be described under 3 headings:

- The User Interface
- Development of the GA
- Evaluation

The software for BGRID is written in Microsoft Visual Basic 5.0 (VB).

The User Interface

At this stage of BGRID's development, the user interface was relatively crude allowing data input only for rectangular shaped buildings with a specified the number of storeys and dimensional constraints. The user could also specify the location of cores and atria within the floor plate. Input was in the form of text and locations of cores and /or atria were fixed using co-ordinates. On one of the screens, the factors which it was intended to build into the final fitness function were presented and the user could rate each of these between 1 and 10 to reflect their importance. However, the fitness function only used one of these factors, rating solutions with large spans higher that those with small spans. The choice of large spans was based on a cost perspective; large span steel buildings have fewer connections, less steel surface area, less labour and hence less cost.

The output displayed the 'best' design solution as determined by the GA after 50 generations. The information was displayed graphically, giving the structural grid. BGRID at this stage only generated uniform grids. If the grid didn't fit the specified footprint, the last bay was adjusted accordingly. Likewise, columns were moved to ensure a column was at each corner of a core and atrium. The user could also look at the structural grid of the 'best' design solutions from each generation so there was database of 50 designs available for examination.

Development of the Genetic Algorithm

The basic form of the GA in BGRID follows the standard architecture of Goldberg (1990) (fig.1).

The aspects of the design that formed the basis of the genotype (an individual in a population) were:

- The grid
- The structural-services integration strategy
- The environmental strategy
- The floor-to-ceiling height

These allow consideration of the first-order design decisions such as the integration of the different grids (planning, structural and constructional), the building depth, which is linked closely to the environmental strategy and the space required for the distribution of services.

The representation chosen for the genotype was real number encoding (fig.2). This minimises the string length thus reducing the search domain and processing time. In fig.2 the first part is the X dimension column locations, the second part the Y dimension and the third part the environmental strategy and the floor to ceiling height.

In determining the population size, previous work was investigated, (DeJong (1988) in which population sizes of 50 – 100 were shown to be sufficient. Based on this evidence a value of 50 was chosen for the population size. When deciding on the number of generations, it was found a relatively small number (50) was sufficient.

As explained above, at the end of stage I, the only factor in the fitness function was the 'large clear span' . This rated solutions with large spans higher than those with small spans. The user was asked to input his/her preferred smallest and largest spans and the system used this information to rate a solution as follows:

$$Fitness = \frac{AS}{LPS} \qquad (1)$$

where AS = average span and LPS = largest preferred span.

The selection technique employed was a roulette wheel and the crossover operator simply performed an exchange of parts between two individuals randomly selected from the mating pool, resulting in two new child individuals. The mutation operator randomly chose one individual (design solution) and replaced one of its genes.The output generated by BGRID was the structural grid, which was displayed graphically. The above describes the development of BGRID before the initial evaluation.

Evaluation of BGRID

As described above, the involvement of practising designers was felt to be a crucial factor in the system's development. Whilst the potential of a GA for conceptual design has been recognised (Hudson and Parmee, 1995; Mathews and Rafiq, 1995; DeJong *et al*, 1999; Khajehpour and Grierson, 1999), the response from those who may be the potential users of such evolutionary design systems has not been recorded. The first stage of BGRID's development took approximately six months and it was at the end of this period that the evaluation of BGRID was conducted. The two main objectives of this evaluation were:

- To elicit information about what potential users might want from a GA based conceptual design DSS;
- To determine if an evolutionary design system, such as BGRID offers an improvement in comparison with current conceptual design procedures.

All of the evaluation sessions began with an explanation of the GA and its use in BGRID as a search tool. A description of the philosophy and the aims of the work followed. Then a demonstration of the BGRID was given. The demonstrations were recorded and later transcribed so that all the information obtained could be analysed.

Experts from architectural, structural, building services and 'research & development' backgrounds evaluated BGRID. The work involved 2 architects, 2 structural engineers and one building services engineer. All the evaluations were conducted on a one to one basis. As the philosophy behind BGRID is an integrated approach to design, it was crucial that those involved with its evaluation came from all the main disciplines. In addition, by using more than one evaluator a broader spectrum of opinion could be obtained.

Evaluation Results

In describing the output from this evaluation, the information obtained will be described first, followed by a description of how this steered BGRID's development in Stage II.

The information obtained was as follows:

- *First order design decisions:* The evaluators offered advice on the first-order design decisions and their order of importance. All said that the architectural and services drivers would take precedence over the structural drivers, implying that the structure could be fitted to whatever was required;
- *Level of detail:* Some suggestions for the future development of BGRID concerned the level of detail. It was suggested that it would be better to provide the user with approximations rather than more 'accurate' calculations which would have to be undertaken using incomplete and assumed information;
- *Costing:* In identifying cost efficient designs, it was recommended that it might be better to use the following parameters as indicators rather than calculating actual costs:
    - Overall building height
    - Number of pieces of steel
    - Uniformity
    - Net/gross floor ratio
    - Wall/floor ratio
- *Importance of input information:* One evaluator said that the two crucial pieces of information at the outset of the design process are the site location and its dimensions, as these have a direct bearing on all the other aspects of the building design. Several other evaluators endorsed this view. This and other information obtained enabled BGRID's data input to be focussed on the crucial requirements.
- *User control:* It was also suggested that allowing the search to generate an optimal solution and then allowing the user to make changes to suit their preferences would further enhance the utility of the system and enable the user to test how good the derived solution actually was.
- *Suitability:* Investigating alternative solutions is an exercise designers go through at the beginning of every project. One of the structural designers felt that the main potential of BGRID is that it enables more solutions to be considered in a short space of time. It was stated that in a typical design process, as many as 10 different configurations may be examined. No doubt in arriving at these 10, other options are implicitly considered and rejected but nevertheless the search is limited compared to what can be achieved with a GA.
- *Time constraints:* Time is a major constraint, which inhibits designers from examining alternatives. Generally, once a satisficing solution has been found, the focus moves onto the details and only if an

insuperable problem arises, is the design altered. This approach can be costly and time-consuming. All the evaluators thought that a system capable of providing the user with alternative designs for further consideration would be extremely useful.

- *Building Services:* The building services engineer felt that the main approach of the system was adequate but he pointed out that it needed to make allowances in the sizing of the cores based on fire regulations. He also envisaged that BGRID could be a useful tool in negotiations with the client, allowing the client to suggest options with the designer then using the tool to show how these would affect the resulting building.
- *Location of cores and atria:* The initial version of BGRID allowed the user to specify where cores and atria would be and then generated grids to fit these locations. The evaluators suggested that a better approach would be to allow a limited degree of flexibility so that the location could be moved to fit the grid, thus providing a larger search space and allowing a greater degree of uniformity in grid spacings.
- *User Interface*: At this stage of development, BGRID's user interface was inevitably fairly limited in its functionality and some of the evaluators made suggestion as to how this could be improved

Overall the evaluators felt that the approach had potential. They particularly liked the ability of the GA to generate a large number of feasible alternatives, effectively using the GA as a search engine rather than an optimisation tool.

The above provided the focus for stage II of BGRID's development. Instead of just providing the user with information regarding designs generated by the GA, the system was to be developed to allow the user to manipulate the GA's solutions to see if further improvements could be made. This would expand the capabilities of BGRID and allow the user to be in more control. Also the evaluation confirmed that the main impact of the process is that it provides an insight into user needs, thus helping to ensure that the system designs for 'real' problems and has a search space that is representative of what occurs in practice.

Stage II Development

This stage of BGRID's development will be described under three headings, which are:

- Development of GA
- The Front End of BGRID
- Evaluation

Development of GA

The development of the GA during stage II focussed on the genetic operators and developing the fitness function. The operators were amended to avoid creating a large number of illegal strings. The following sections will briefly describe each of the operators and the fitness function. A more detailed description can be found in Sisk (1999).

Selection

As stated earlier, the selection technique employed in BGRID's GA is a roulette wheel. An improvement was made by employing the Standard Fitness Method (Bradshaw & Miles, 1997). This ranks the population using the raw fitness values and then allocates predetermined slot sizes on the roulette wheel. The slot sizes are calculated using just one parameter, the standard deviation of the normal distribution. This allows the selective pressure to be fixed before runtime. This was important in this work due to the potentially large number of high fitness solutions being generated in the initial seeded population. Using the Standard Fitness Method, a reasonable amount of bias is exerted towards the best individuals thus ensuring the search progresses even when the overall fitness of the population is high.

Crossover

Using a real number alphabet does not mean the traditional forms of crossover cannot be used. These only require a list of variables, which are used to form a string. However, because the GA in BGRID has to deal with variable length strings (due to the different grid sizes), the traditional genetic operators need to be amended. Each individual chromosomal string within BGRID can be viewed as being made up of three parts. The first part contains the x co-ordinates of the columns, the second the y co-ordinates. The third part consists of the remaining three aspects of the design (the design option, the environmental strategy and the clear floor-to-ceiling height) (fig.2).

The crossover operator needed to be amended to avoid creating illegal strings and also to accommodate the fact that various sections of the genome need to be operated on separately. For example, if the x co-ordinates of one string were combined with the y co-ordinates of another string, the resulting child string may be illegal because the column positions may not correspond to the building's dimensions. Also, the operator has to deal with variable length strings hence, a one-point crossover operator is applied to each of the three parts of the string individually.

Mutation

Mutation involves initially assigning a randomly generated value between zero and one to each gene or bit within each chromosome. The mutation operator then reviews every assigned value to see if it is greater than the probability of mutation. If this is the case then a new gene is generated which replaces the old gene. In this GA, the value of the gene that replaces the old gene within the first two parts of the string is limited within the boundaries of the preceding and the succeeding bits.

The Fitness Function

The fitness function was changed with the fitness function now including constraint checks as follows:

- Is overall height is less than any height restriction;
- Is design option is compatible with chosen structural system, particularly with respect to span lengths;
- Check the uniformity of the grid.

If the above are not satisfied a penalty function is applied to the individual's fitness (Sisk, 1999).

The second part of the fitness function deals with the soft constraints. BGRID deals with these by assessing each individual relative to the other individuals generated up to that point. That is, the worst and the best examples of each criterion are used to determine how good the design solution is for the particular aspect.

$$fiobj = \frac{(fi - fibad)}{(figood - fibad)} \qquad (2)$$

fiobj	=	fitness of individual component
fibad	=	value of worst individual generated up to that point
figood	=	value of best individual generated up to that point
fi	=	value of evaluated parameter for individual within the current *population*

The objective is to maximise the value of *fiobj*.

To allow user control of the search, the user can alter the weights of the three main parts of the fitness function to reflect their importance for a given design. The weights range from 0 to 4, with 0 being *unimportant* and 4 being *highly significant (fig.3).*

The three components are:

- Large clear span – large spans are often required to enhance the flexibility of space;
- Minimising Cost – cost-efficient solutions are identified using the following parameters:
  - Total weight of floor
  - Overall building height
  - Net/gross floor ratio
- Maximising Use of Natural Resources - solutions that can maximise the use of natural daylight and natural ventilation are identified using the following parameters:
  - Depth of space
  - Clear floor-to-ceiling height
  - Site location

This ends the description of the stage II development of the GA. A full description can be found in Sisk (1999).

The Second Stage User Interface

The development of BGRID focused on addressing the three basic requirements for any conceptual design DSS, namely simplicity, speed and transparency. Hence, the input data is kept to a minimum and arranged as follows:

1. Geometrical information (plan dimensions and number of floors);
2. Site location (urban, Greenfield, etc), planning restrictions such as maximum allowable height and minimum floor-to-ceiling heights;
3. Location of cores and atria, fire exits are also considered at this stage;
4. Dimensional constraints (see below).

The dimensional constraints determine the grids that can be generated by the GA. The user is asked to input the various grid dimensions (Fig. 4). The ranges of these are strictly limited to reflect the actual constraints that exist. These are fixed by such things as sizes of available building components. etc. In order to increase the transparency of the system, the user can access and edit all the design information within BGRID. As recommended by the evaluators, BGRID sizes structural elements using approximate methods, such as span/ depth ratios. Currently BGRID only contains information on steel structural systems. It is intended to include complementary information on concrete systems at a later date.

The next part of the user interaction concerns the search process and how to guide this by altering the fitness function weights. As described above, the fitness function has 3 components, the aim of these being to minimise cost, maximise clear spans and maximise the use of natural resources. The output information generated by BGRID is grouped under three headings, which are:

Statistical Information: Maximum, average and minimum fitness versus the generation number is displayed on graphs at the end of each search. These allow the user to monitor the performance of the GA and encourage informed decision-making, helping to expand the user's understanding of the search space.

Initial design Solutions: BGRID stores the 'best' design solution for each generation. These are stored in the form of a design summary (fig.5). This provides the user with a good range of different designs which can help the designer to investigate design alternatives.

Best Design Solutions: BGRID enables the user to view the 'best' design solution for each of the short, medium and long span structural systems in a similar format to Fig. 5. The user can edit the design solutions, by, for example moving the location of the atrium or changing the clear floor-to-ceiling height. BGRID automatically checks any amendments to ensure that no constraints are violated and re-evaluates the fitness.

Evaluation – Stage II

This second evaluation took place after 18 months of development. The form of the evaluation was similar to that used for stage I. The main people involved were an architect and a structural engineer, both of whom had participated in the previous evaluation. They were able to see that their earlier suggestions had been incorporated into BGRID. This is important. It shows that their comments are valued and that their interaction is useful.

Also, during the evaluation two additional evaluators from Corus (a steel producer) and one from SCI were used to obtain an independent assessment of BGRID. All three are structural engineers. One of the Corus people felt that BGRID should include whole-life costs but they also recognised the difficulties in generating absolute costs at the conceptual design stage when information is ill defined. In reality, actual costs and pricing aren't directly connected and it is difficult to formulate a relationship between the two. This emphasises the advantage of the approach used in BGRID of determining relative costs (using cost drivers) instead of absolute costs. The SCI evaluator ran some test cases through BGRID, with satisfactory results being obtained. Both the Corus and SCI evaluators felt that with further development, BGRID would form a useful, commercial product and attempts were made by them to obtain finance to further its development. These unfortunately came to nothing because of the high value of sterling affecting the finances of the UK steel industry.

The response received from the evaluators was very positive. They could see the potential of BGRID. From the evaluation it became apparent that there was a need for some post-processing because of the large amount of output information generated by BGRID. It was suggested that it would be beneficial if the user was able to compare individual pieces of information, e.g. steel weight versus overall height of building. By doing this, one could see if there were any patterns or if there was an option that gave for example, the lowest steel weight and height.

Long Term Evaluation

In addition to the above evaluation, BGRID underwent a long-term evaluation in a design office where it was assessed by two structural engineers, one of whom was involved with stages 1 and 2 of the evaluation. A diary was provided for the evaluators to enter comments. Copies of BGRID were left in the design office for approximately three months. The evaluators used real designs, projects which generally were at the detailed stage of design. This was so comparisons between the designs used and that generated by BGRID could be made.

A typical test case used was:

Building dimensions:	60 x 18.2 m		
Function:	Office Building		
Location:	suburban		
Number of stories:	5		
Height restriction:	none		
Minimum floor-to-ceiling height:	3.0 m		
Number of cores:	2		
Number of atria:	none		
Location of cores:	(7.5, 18.2) and (52.5, 18.2)	X,Y co-ordinates of upper right hand corner relevant to bottom left-hand corner of building (0,0)	
Size of cores:	7.5 x 7.5 m		
Dimensional constraints:	modular grid:		1500 mm
	critical grid:		3000 mm
	preferred smallest bay dimension:		7500 mm
	preferred maximum bay dimension:		18200 mm

The evaluating criteria weight factors used in the search were as follows:

- Minimising cost – 4 (extremely important);
- Maximising clear span – 1 (not so important);
- Maximising use of natural resources – 1 (not so important).

The 'best' design solution generated by BGRID for medium span solutions and the design used by the evaluators is shown in Table 1. As can be seen both designs are similar, with the only major difference being the environmental strategy proposed. The reason for this was because air-conditioning was the only option available to the design team due to the client's specifications.

The above test case demonstrated BGRID's ability to generate valid design solutions for 'real' design problems using a GA-based DSS.In addition, the evaluators provided a list of the requirements that they felt would improve BGRID. This shows the importance of long-term evaluation, as the majority of these points were not raised during stage 1 and 2 of the evaluation process.

- More explanation facilities are needed;
- The system should allow users to specify whether or not the building dimensions could be adjusted and whether the location of the cores could be adjusted. This was important because in practice the structural engineer may not have the option to adjust them and would have to work within their constraints;
- Evaluators felt that BGRID tended to underestimate the weight of steel.

In the summer of 2002, BGRID was demonstrated to 8 focus groups of practising designers. The groups included structural and building services engineers and architects from throughout the UK. Before the presentation it was explained that BGRID was a research demonstrator and that if commercial software were to be provided, it would have a better quality user interface and links to other design software. A total of 63 designers participated. Some of them hated the thought of using software for conceptual design but the majority (68%) said they thought that such a tool would be very useful and they would personally utilise it during their work.

Discussion

From the above it can be seen that much was gained from the interaction with the designers. They for example determined a suitable level of accuracy, provided constraints to restrict the search space, defined a form of cost function, asked for access to a wide range of possible solutions, a method of editing these solutions and an evaluation routine which they could adjust to suit the problem under consideration. Also, and most importantly, they provided an valid assessment of the technique so that there is now a reasonably robust body of research which says that an evolutionary computing based search engine is a suitable tool for this type of design problem.

It is instructive to briefly compare this work with that of Khajehpour and Grierson (1999) and Rafiq et al (1999). Both of these used a GA but had a much less constrained search space than BGRID. For example both allowed the number of storeys to vary whereas in BGRID this was fixed. The designers who collaborated on the BGRID work said that the number of storeys would be determined by planning restrictions, the client's floor space requirements and the available land space so this was not worth including.

Both of the above systems have features that don't appear in BGRID. For example Khajehpour and Grierson present the results of their search in terms of Pareto surfaces. This clearly transmits to the designer the trade off between the various options. A good alternative to this would be to use the COGA filtering process (Parmee, 1998). A designer would be extremely unlikely to request this type of facility as they would not be aware of the technology. It should be noted that Khajehpour and Grierson do not allow the user to alter the evaluation function in any way so there is no way the designer can influence the search. Rafiq et al use a Neural Network (NN) to work out section sizes and material weights for the evaluation function. Again a practising designer would be unlikely to be aware of NNs however the solution used in BGRID of span / depth ratios is more than sufficiently accurate for conceptual design. So although potential user involvement is useful, there is a need for a strong technical input from the system developers.

Conclusions

A research project to investigate the required functionality and suitability of BGRID, an evolutionary computing based conceptual design tool for the design of commercial, office type buildings is described. BGRID's iterative development has been driven by the information elicited, through its evaluation by practising architects and engineers. From the very early stages of BGRID's development, the onus was on developing a novel, yet practical, design aid. The research has been undertaken in collaboration with practising designers and it is demonstrated how such people can have a significant and constructive input to advanced IT research. Also it is shown that the involvement of such people provides an assessment of the worth of the research and the resulting techniques. However, it is also shown that because designers are not fully aware of all the available techniques and advanced research results, that there will always be a requirement for a strong technological steer from the researchers and hence a need for work on technique development as well as the more industrially based type of research described in this paper.

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Figure Captions

Table Caption

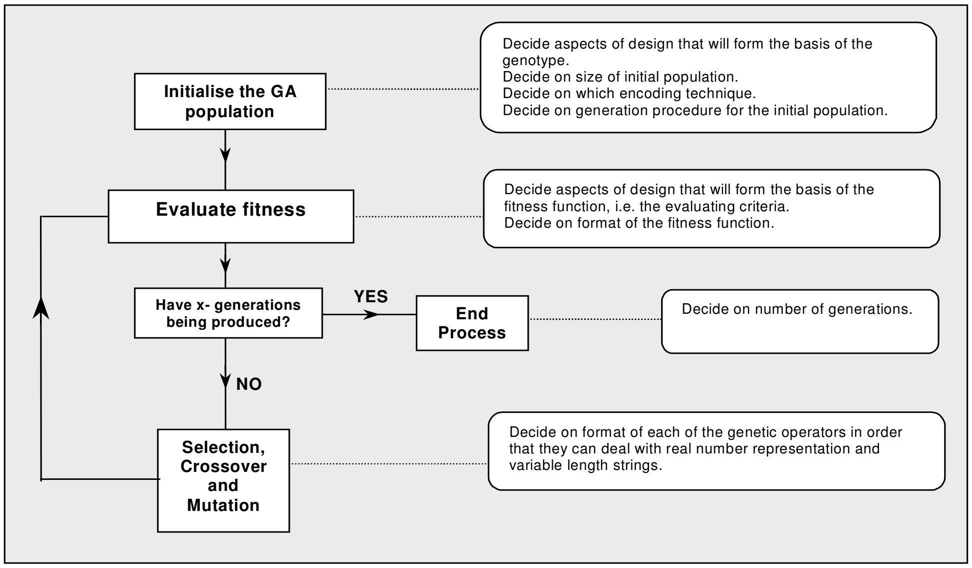
Initialise the GA population
Decide aspects of design that will form the basis of the genotype.
Decide on size of initial population.
Decide on which encoding technique.
Decide on generation procedure for the initial population.
Evaluate fitness
Decide aspects of design that will form the basis of the fitness function, i.e. the evaluating criteria.
Decide on format of the fitness function.
Have x- generations being produced?
YES
End Process
Decide on number of generations.
NO
Selection, Crossover and Mutation
Decide on format of each of the genetic operators in order that they can deal with real number representation and variable length strings.

Fig.1

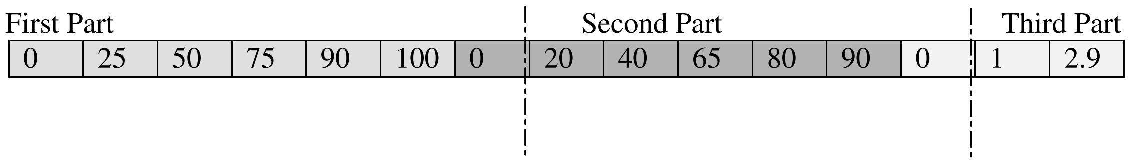
First Part
Second Part
Third Part
0
25
50
75
90
100
0
20
40
65
80
90
0
1
2.9

Fig.2

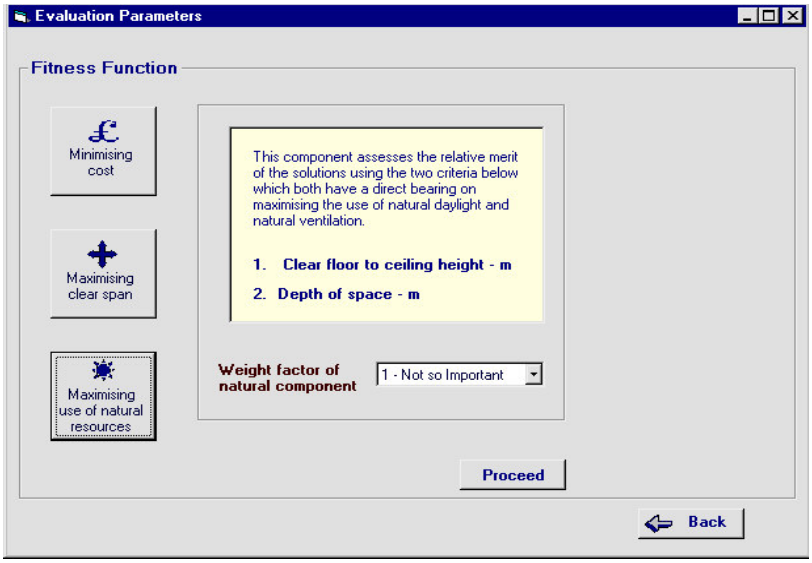
Evaluation Parameters
Fitness Function
Minimising cost
Maximising clear span
Maximising use of natural resources
This component assesses the relative merit of the solutions using the two criteria below which both have a direct bearing on maximising the use of natural daylight and natural ventilation.
1. Clear floor to ceiling height - m
2. Depth of space - m
Weight factor of natural component
1 - Not so Important
Proceed
Back

Fig.3

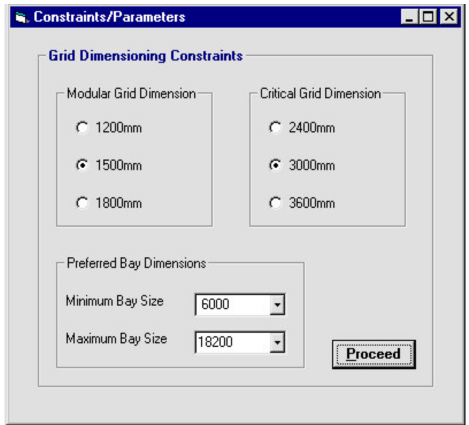
Constraints/Parameters
Grid Dimensioning Constraints
Modular Grid Dimension
1200mm
1500mm
1800mm
Critical Grid Dimension
2400mm
3000mm
3600mm
Preferred Bay Dimensions
Minimum Bay Size
6000
Maximum Bay Size
18200
Proceed

Fig.4

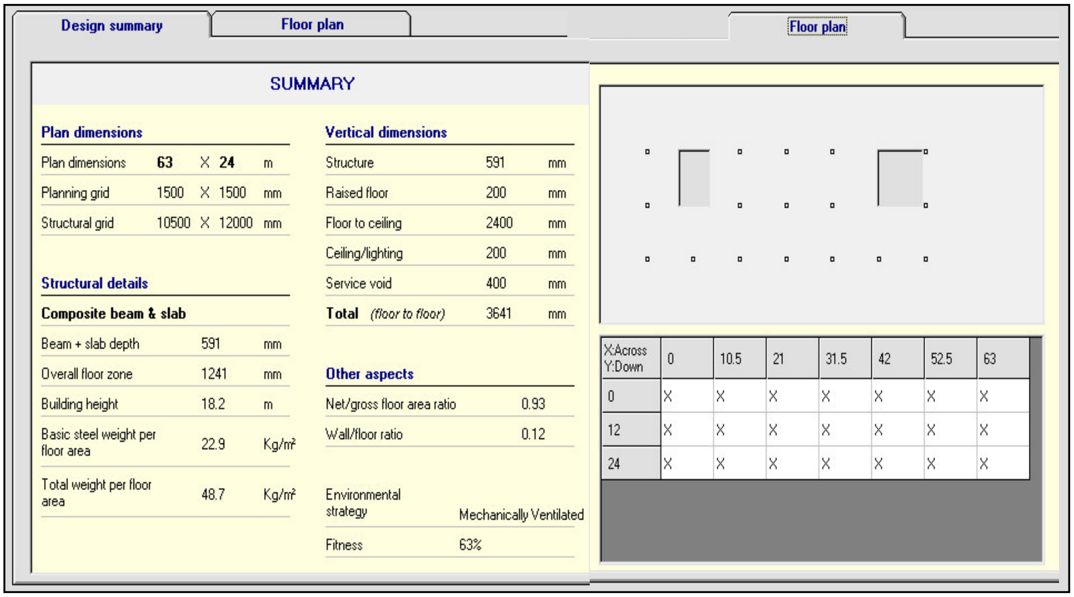
Design summary
Floor plan
Floor plan
SUMMARY
Plan dimensions
Plan dimensions 63 X 24 m
Planning grid 1500 X 1500 mm
Structural grid 10500 X 12000 mm
Structural details
Composite beam & slab
Beam + slab depth 591 mm
Overall floor zone 1241 mm
Building height 18.2 m
Basic steel weight per floor area 22.9 Kg/m²
Total weight per floor area 48.7 Kg/m²
Vertical dimensions
Structure 591 mm
Raised floor 200 mm
Floor to ceiling 2400 mm
Ceiling/lighting 200 mm
Service void 400 mm
Total (floor to floor) 3641 mm
Other aspects
Net/gross floor area ratio 0.93
Wall/floor ratio 0.12
Environmental strategy Mechanically Ventilated
Fitness 63%
X:Across Y:Down
0 10.5 21 31.5 42 52.5 63
0 X X X X X X X
12 X X X X X X X
24 X X X X X X X

Fig.5

	Evaluator's Design	**BGRID Design**
Structural system	Composite beam and slab Construction	Composite beam and slab Construction
Environmental strategy	Air-conditioning	Mechanical ventilation
Grid	8 bays – 7.5m x-direction 2 bays – 10.7 and 7.5m y-direction	8 bays – 7.5m x-direction 2 bays – 9.0m y-direction

Table 1